

Annual Summary
Construction and Verification of a Wasatch Front Community Velocity Model:
Collaborative Research with San Diego State University and the University of Utah

Grant Award Number 05HQGR0011

Harold Magistrale

Kim Olsen

Department of Geological Sciences

San Diego State University

5500 Campanile Drive

San Diego, CA 92182-1020

phone: 619 594 6741

fax: 619 594 4372

email: magistra@mail.sdsu.edu

INVESTIGATION UNDERTAKEN.

A fundamental problem in assessing seismic hazard from potential future earthquakes is determining the distribution, amplitude, frequency characteristics, and duration of strong ground motion from potential future earthquakes. These ground motion characteristics are influenced by subsurface velocity-density structure (especially at shallow depths), and by the influence of 3D geologic structures, such as sediment-filled basins. The population of Utah is concentrated in such basins at the foot of the Wasatch Front, which is formed by the active, normal Wasatch fault, and is a likely source of future earthquakes. To help develop earthquake ground-shaking microzonation hazard maps of the region, we are constructing of a 3D Wasatch Front community velocity model (CVM) that can be used in numerical ground motion simulations. The work will include verification of the model by performing numerical simulations of local earthquake ground motions in the model, and comparing those results to observations. The work described here is in progress.

The area of the Wasatch Front CVM encompasses the Salt Lake City-Ogden-Provo urban corridor (within which more than 75% of the population of Utah resides). This area includes the Salt Lake basin, the Weber basin to the north, the Utah basin to the south, and the Tooele and Rush basins to the west and southwest, respectively. The Salt Lake basin has the most data available. There are fewer data available for the other four basins but those data are adequate to broadly characterize the basins.

The Wasatch Front CVM is being assembled from existing near-surface data including lithologic well logs, S-wave velocity measurements, sonic logs, and seismic reflection lines.

The Salt Lake basin geometry is characterized by the depths to the interface between unconsolidated and semi-consolidated sediments (known as R1), the interface between the semi-consolidated and consolidated sediments (R2), and the depth to basement (R3) (Hill et al., 1990). The R1 depths are constrained by 125 well logs compiled by Arnou et al. (1970). R2 is defined by the gravity modeling of Radkins (1990), with constraints from 40 well logs and three seismic reflection lines. Constraints on the attitude of R3 and basement rock velocities come from the refraction results of Bashore (1982). Additional information on sediment thickness from potential field surveys, seismic refraction, and well logs are available from Mattick (1970). Sediment densities and P-wave velocities from well logs and seismic reflection results are given

in Radkins et al. (1989) and Hill et al. (1990). We are building R1, R2, and R3 model surfaces (see Figure 1).

McDonald and Case (2005) have compiled a database of shallow Vs, cone penetrometer, and other geophysical observations in the Salt Lake basin that we are using in the model. Near-surface seismic velocities in the Salt Lake basin are available from 22 Vp and Vs borehole logs to about 55 m depth published by Tinsley et al. (1991) and Williams et al. (1993), Vs logs of geotechnical boreholes (≤ 90 m deep), and surface wave studies by Schuster and Sun (1993; 28 sites, Vs to 40 m depth) and Bay et al. (2004, 2005; 45 sites, Vs to 30-60 m depth). Ashland and Rollins (1999), Ashland (2001), Ashland and McDonald (2003) and Bay et al. (2005) defined and mapped soil site response units based on grain size and Vs30 measurements. Wong et al. (2002a) developed generalized Vs-density profiles for 5 of these soil site response units, four of which were subsequently used by Wong et al. (2002b). We are integrating these site response units and borehole logs into the CVM. Following Wong et al. (2002a) we are experimenting with extending the surface site response units to the base of the unconsolidated sediments (in contrast to extending them to a shallower depth). This effort is constrained by models of Vs at four locations in the basin to depths of ~ 100 to ~ 350 m from refraction/reflection data collected using a shear-wave vibrator source (W. Stephenson, personal communication, 2005).

Data for the Weber, Utah, Tooele, and Rush basins includes water well definition to the base of unconsolidated sediments compiled by the UGS for the Wong et al. (2002b) and Solomon et al. (2004) studies (G. Christenson, personal communication, 2003). Mabey (1992) shows thicknesses of low-density sedimentary rocks in the Weber and Utah basins, inferred from gravity data. McNeil and Smith (1992) inferred depth to bedrock from gravity, constrained by seismic reflection data, in the Weber basin. There are Utah and Tooele basin gravity studies by students of K. L. Cook at the University of Utah and A. Benson at BYU. In the Weber, Utah, Tooele, and Rush basins we are testing CVM sediment seismic velocities inferred from densities, and comparing those velocities to the better-determined velocities from the Salt Lake basin.

Sub-basin crustal velocities are obtained from Bashore (1982) and Smith et al. (1989) and references therein. Regional 3D crustal tomography results based on local earthquake travel times can be obtained from Lynch (1999) and some recent results (A. DeNosaquo, personal communication, 2005). Moho attitude and upper mantle velocities are given in Loeb (1986), Loeb and Pechmann (1987), and Smith et al. (1989).

In creating the Wasatch Front CVM, we are using the method of Magistrale et al. (2000) used to construct a southern California CVM. The basins are parameterized as a set of objects and rules implemented in a computer code that generates seismic velocities and density at any desired point. The objects are typically stratigraphic surfaces constructed from geological, geophysical, and geotechnical data, and the rule is Faust's relation $V_p = k(da)^{1/6}$ where V_p is P-wave velocity, d is the maximum depth of burial of the sediments, a is the sediment age, and k is a constant. Age at any point in a basin can be interpolated from the surfaces. The constant k is calibrated for each surface by comparison to well sonic logs and seismic refraction surveys. Density is derived from V_p using a standard relation; density is used to find Poisson's ratio and Vs is calculated from the V_p and Poisson's ratio.

The shallow basin velocities are directly constrained by geotechnical borehole logs and detailed surface site response unit mapping based on surface geology and Vs30 measurements. If queried at a borehole location, the model returns the original borehole measurement; if the query

is away from a borehole, the model returns a value that is a weighted sum of nearby boreholes and a mean velocity profile of that site response type.

RESULTS

We are constructing the model elements; two are shown in figure 1.

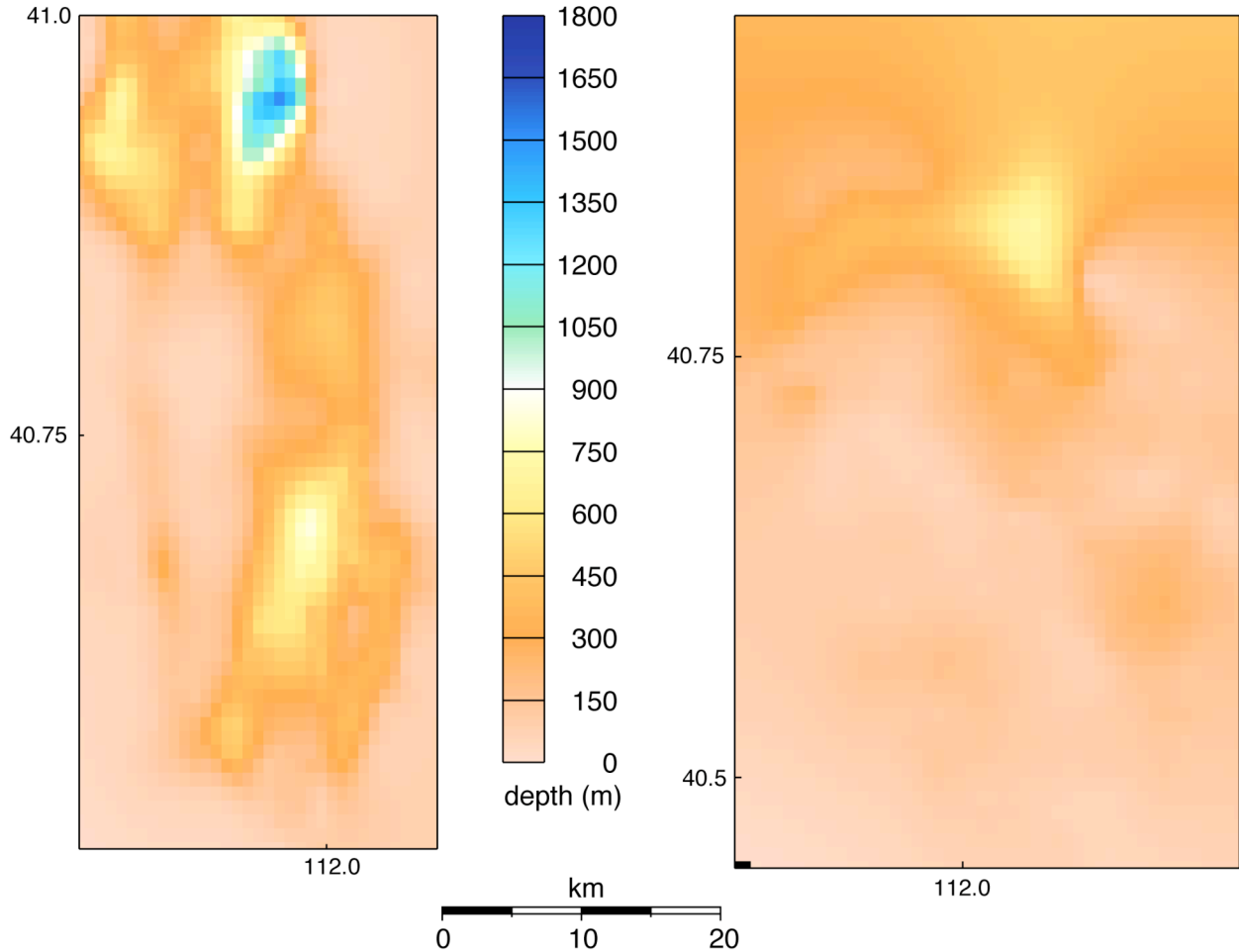


Figure 1. Preliminary model elements representing depth to R1 (left panel; data from Arnow et al., 1970), and depth to R2 (right panel; data from Radkins, 1990) (see depth scale bar) in the Salt Lake basin. R1 is the interface between unconsolidated and semi-consolidated sediments and R2 is the interface between the semi-consolidated and consolidated sediments. Properties are interpolated between the model elements.

NON-TECHNICAL SUMMARY

The Salt Lake City area is adjacent a major fault system that will produce earthquakes in the future. This project is to use existing geological information to construct a computer model of the earth in the Salt Lake City area. This model will be very useful in computer simulations of the

ground shaking caused by the potential future earthquakes. Those simulated ground shaking calculations will help in developing engineering standards and in planning emergency response.

REFERENCES CITED

- Arnow, T., R. Van Horn, and R. LaPray (1970). The Pre-Quaternary surface in the Jordan Valley, Utah, *U.S. Geol. Surv. Pro. Pap.* 700-D, D257-D261.
- Ashland, F.X. (2001). Site-response characterization for implementing SHAKEMAP in northern Utah, *Utah Geol. Surv. Rept. of Investigation* 248, Utah Geological Survey, 10 pp., 2 pl.
- Ashland, F.X. and G.N. McDonald (2003). Interim map showing shear-wave-velocity characteristics of engineering geologic units in the Salt Lake City, Utah, metropolitan area, *Utah Geol. Surv. Open-File Rept.* 424, CD-ROM, 43 pp., 1 pl.
- Ashland, F.X. and K. Rollins (1999). Seismic zonation using geotechnical site-response mapping, Salt Lake Valley, Utah, *Final Tech. Rept., Award No. 1434-HQ-97-GR-03126, National Earthquake Hazards Reduction Program, U.S. Geological Survey*, 33 pp.
- Bashore, W.M. (1982). Upper crustal structure of the Salt Lake Valley and the Wasatch fault from seismic modeling, M.S. Thesis, University of Utah, Salt Lake City, Utah, 95 pp.
- Bay, J., J. Gilbert, F. X. Ashland, G. McDonald, and K. L. Pankow (2004). 2003 SASW shallow shear-wave velocity results, talk presented at *Earthquake Hazards in Utah: Improving Our Understanding*, February 26, 2004, Salt Lake City, Utah.
- Bay, J., F.X. Ashland, and K.L. Pankow (2005). Shallow shear-wave velocity profiling of poorly characterized earthquake site response units in urban Salt Lake Valley, *Final Tech. Rept., National Earthquake Hazards Reduction Program, U.S. Geol. Surv.*, in preparation.
- Hill, J., H. Benz, M. Murphy, and G. Schuster (1990). Propagation and resonance of SH waves in the Salt Lake Valley, Utah, *Bull. Seism. Soc. Am.* **80**, 23-42.
- Loeb, D.T. (1986). The P-wave velocity structure of the crust-mantle boundary beneath Utah, M.S. Thesis, University of Utah, Salt Lake City, Utah, 126 pp.
- Loeb, D.T. and J.C. Pechmann (1986). The P-wave velocity structure of the crust-mantle boundary beneath Utah from network travel time measurements, *Earthquake Notes* **57**, 10.
- Lynch, D.P. (1999). Three-dimensional finite difference tomography of the Basin and Range - Colorado Plateau - Rocky Mountain transition using earthquake and controlled source data, M.S. Thesis, University of Utah, Salt Lake City, Utah, 155 pp.
- Magistrale, H., S. Day, R. Clayton, and R. Graves (2000). The SCEC southern California reference 3D seismic velocity model version 2, *Bull. Seism. Soc. Am.* **90** (6B), S65-S76.
- Mabey, D.R. (1992). Subsurface geology along the Wasatch Front, in *Assessment of Earthquake Hazards and Risk Along the Wasatch Front, Utah*, P.L. Gori and W.W. Hays (Editors), *U.S. Geol. Surv. Pro. Pap.* 1500-A-J, C1-C16.
- Mattick, R. E. (1970). Thickness of unconsolidated to semiconsolidated sediments in Jordan Valley, Utah, *U.S. Geol. Surv. Pro. Pap.* 700-C, C119-C124.
- McDonald, G.N. and W.F. Case (2005). Geologic hazards databases, *Utah Geol. Surv. Rept.*, CD-ROM., in preparation.
- McNeil, B.R., and R.B. Smith (1992). Upper crustal structure of the northern Wasatch Front, Utah, from seismic reflection and gravity data, *Utah Geol. Surv. Contract Rept.* 92-7, 62 pp., 6 plates.
- Radkins, H., M. Murphy, and G.T. Schuster (1989). Subsurface map and seismic risk analysis of the Salt Lake Valley, *Utah Geol. Min. Surv. Open-File Rept.* 152, 82 pp., 3 pl.
- Smith, R. B., W. C. Nagy, K. A. Julander, J. J. Viveiros, C. A. Barker, and D. A. Gants (1989). Geophysical and tectonic framework of the eastern Basin and Range-Colorado Plateau-Rocky Mountain transition, in *Geophysical Framework of the Continental United States*, L.C. Pakiser and W. D. Mooney (Editors), Geological Society of America Memoir 172, Boulder, Colorado, 205-233.

- Solomon, B.J., N. Storey, I. Wong, W. Silva, N. Gregor, D. Wright, and G. McDonald (2004). Earthquake-hazards scenario for a M 7 earthquake on the Salt Lake City segment of the Wasatch fault zone, Utah, *Utah Geol. Surv. Spec. Study 111*, CD-ROM, 59 pp., 6 pl.
- Schuster, G. T. and Y. Sun (1993). Surface wave inversion of near surface shear velocities in Salt Lake Valley, *U.S. Geological Survey Technical Report 1434-92-G-2175*, 169 p.
- Tinsley, J. C., K. W. King, D. A. Trumm, D. L. Carver, and R. A. Williams (1991). Geologic aspects of shear-wave velocity and relative ground response in Salt Lake Valley, Utah, in *Proceedings of the 27th Symposium on Engineering Geology & Geotechnical Engineering*, J. P. McCalpin (Editor), Pocatello, Idaho, 25-1-25-9.
- Williams, R.A., K.W. King, and J.C. Tinsley (1993). Site response estimates in Salt Lake Valley, Utah, from borehole seismic velocities, *Bull. Seism. Soc. Am.* **83**, 862-889.
- Wong, I., W. Silva, S. Olig, P. Thomas, D. Wright, F. Ashland, N. Gregor, J. Pechmann, M. Dober, G. Christenson, and R. Gerth (2002a). Earthquake scenario and probabilistic ground shaking maps for the Salt Lake City, Utah, metropolitan area, *Utah Geol. Surv. Misc. Pub. MP-02-5*, 78 pp., 9 plates.
- Wong, I., W. Silva, N. Gregor, D. Wright, F. Ashland, G. McDonald, S. Olig, G. Christenson, and B. Solomon (2002b). Earthquake scenario ground shaking maps for the central Wasatch Front, Utah, in *Proceedings of the 7th U.S. National Conference on Earthquake Engineering*, Boston, Mass., July 21-25, 2002, CD.